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Davis, CA

FSCBG MODEL COMPARISONS - 1974 RENNIC CREEK TRIALS

FPM 94-12
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Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.

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FSCBG MODEL COMPARISONS -

1974 RENNIC CREEK SPRAY TRIALS

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Summary

FSCBG simulations are presented for the aerial application of dyed fuel oil from a helicopter equipped with hydraulic nozzles. Five spray trials were performed by the USDA Forest Service in October 1974 at the Rennic Creek in Lolo National Forest, Montana. Deposition data are available from sampling rows located in the open as well as beneath the forest canopy. Deposition variables determined during analysis of the field test data are compared to FSCBG simulations of ground deposition for each of the trials. Average correlation of FSCBG predictions to the field data is R^2=0.88 in open terrain and R^2=0.85 in forest terrain.

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1. Introduction

This paper is the fourth in a series of validation studies to be accomplished in 1993-1995 using the Forest Service Cramer-Barry-Grim (FSCBG) aerial spray model (Teske et al. 1993) and its near-wake Agricultural Dispersal (AGDISP) model (Bilanin et al. 1989). Recent field tests of several aerial spray scenarios have been performed with a variety of aircraft. Ground deposition data from each of these tests are available for comparison with FSCBG and AGDISP simulations. This paper is concerned with a test performed in October 1974 to observe the deposition of dyed fuel oil atomized from hydraulic nozzles. A Bell G-3 helicopter was used in the trials. This paper follows the format of our previous reports (MacNichol and Teske 1993a, 1993b, 1994).

The USDA Forest Service in cooperation with the U.S. Army has developed FSCBG incorporating AGDISP as its near-wake model. FSCBG predicts the transport and behavior of pesticide sprays released from aircraft, influenced by the aircraft wake and local atmospheric conditions, through downwind drift and deposition to total accountancy and environmental fate. The AGDISP near-wake representation solves a Lagrangian system of equations for the position and position variance of material released from each nozzle on the aircraft. The FSCBG far-wake representation begins with the results of AGDISP at the top of a canopy or near the ground, and solves a Gaussian diffusion equation to recover ground deposition. FSCBG includes an analytic dispersion model for multiple line sources oriented in any direction to the wind, an evaporation model for volatile spray components, a canopy penetration model for forest canopy interception, and an accountancy model to recover environmental fate of released material.

Drop size distributions give the mass distribution of material as it is atomized by each nozzle. Drops containing volatile material (such as water) begin to evaporate immediately upon entering the atmosphere, with the local temperature, relative humidity and relative wind speed determining the evaporation rate. The presence of the aircraft wake (with its vortical structure) may move material to unanticipated locations. Ambient winds superimpose additional horizontal velocity vectors on the spray material. Canopy deposition removes spray material from the air and prevents nonvolatile components from reaching the ground. Every aspect of the spray process is affected by the size and significance of atmospheric and aircraft-generated turbulence.

Meteorological calculations generate the background wind speed, temperature and relative humidity profiles. Evaporation calculations track the time rate of decrease of drop size. Canopy calculations remove additional material through impaction on vegetation. Near-wake calculations follow the behavior of released spray near the aircraft, and when out of wake influence or at the top of the canopy, hand off to the dispersion calculations to predict the dosage, concentration and deposition at user-designated downwind locations.

Technical aspects of the FSCBG model are discussed in Teske et al. (1993). Previous comparisons with data include downslope drift in open terrain (Barry et al. 1993), a drift study over desert (Boyle et al. 1975), canopy penetration in Southern pine (Rafferty et al. 1982), open terrain and canopy penetration in Douglas-fir (Teske et al. 1991), eastern oak (Anderson et al. 1992), and Gambel oak (Rafferty and Grim 1992), in addition to our three previous reports (MacNichol and Teske 1993a, 1993b, 1994).

The aircraft spray trials referred to in this paper took place on October 23, 1974 on sloping terrain in the Rennic Creek drainage, Lolo National Forest, Montana. The USDA Forest Service (FS), Forest Pest Management, performed five trials to evaluate the deposition

characteristics, in the open and under a canopy, of fuel oil containing Automate B Red Dye, aerially sprayed through a helicopter spray system. Each trial consisted of one pass over six parallel card lines, three in open terrain and three under the forest canopy, as described in Figure 1.

Program objectives were to use all available technology to reduce losses caused by the Douglas-fir tussock moth and to develop and evaluate forest and pest management systems designed to prevent or suppress infestations (Dumbauld, Rafferty and Bjorklund 1977). Data from the trials were analyzed by the H. E. Cramer Company, Inc. to study the effectiveness of a mathematical canopy penetration model developed previously for the U.S. Army Dugway Proving Ground (Grim and Barry 1975). This model in part was a precursor of FSCBG. Among the recommendations made by Dumbauld, Rafferty and Bjorklund (1977) in their evaluation of the Rennic Creek test data were studies designed to further develop and verify models for predicting spray behavior, although the original intent of the field study was not model evaluation.

Meteorological data from the trials were reported by Dumbauld, Rafferty and Bjorklund (1977). Printflex deposit cards were analyzed using the Automatic Spot Counting and Sizing System (ASCAS) (Young, Luebbe and Barry 1977) at Los Alamos National Laboratory. Deposition data are summarized by Barry (1974). Deposition data for each trial include deposition density in milligrams per square meter (mg/sq m) and volume in ounces per acre (oz/ac). Although the data were available, we did not analyze for spray drop density, even though mass through foliage may be suspect at times, and may be inferior to numbers of drops.

2. Field Trials Summary

2.1 Spray Site and Spray Deposit Sampling

2.1.1 Spray Site Description

A diagram of the test site (Figure 1) shows the sloping terrain and sampling card lines relative to open and forest areas. The open area was a clear cut. The open/forest boundary was abrupt as is the usual case in clear cut areas. The trials were conducted at the Rennic Creek test site in Lolo National Forest, Montana.

According to Barry (1974), the Rennic Creek test site has a South to Southeast aspect with a 30 to 45 percent slope. The open terrain had few surface rocks, with no large rocky outcrops. The habitat type was Douglas-fir and ninebark. Ground cover ranged from ninebark to sparse pinegrass and low forbs.

The overall forest canopy was relatively uniform with only a few scattered openings (Dumbauld, Rafferty and Bjorklund 1977). The stand was 95 percent Douglas-fir, with the remainder of the trees being larch, lodgepole pine or ponderosa pine. The forest was a two-layer forest with a well-developed overstory and a stagnated understory. Although there were approximately 600 trees per acre, slightly more than half of the trees had little or no foliage at the time of the trials (Dumbauld, Rafferty and Bjorklund 1977). Table 1 summarizes the forest characteristics; a detailed description of the characteristics shown is given in Dumbauld, Rafferty and Bjorklund (1977).

2.1.2 Sampling Line Description

Six spray deposit sample lines were set parallel to each other at approximately 64m apart. Three card lines were in open terrain (henceforth designated "open rows") and three were under the forest canopy ("forest rows").

Printflex cards were positioned along the ground every 6.3m. Card lines were 28 positions long (171m).

2.2 Meteorology Measurements

Each trial consisted of one pass over all six card lines. There were five trials.

Wind speed and direction were measured at 2m and 18.6m on a crank-up tower located in open terrain (shown by the filled triangle in Figure 1), and on a 2-meter mast located within the forest (shown by the open triangle in Figure 1). Temperature was measured within and above the forest using a balloon-borne wiresonde located near the 2-meter mast, shown by the filled square in Figure 1. Detailed meteorological data is given by Dumbauld, Rafferty and Bjorklund (1977) and Barry (1974).

Table 2 summarizes the meteorological data for each trial. The trials were all conducted on October 23, starting at 10:32AM and ending at 2:57PM. Relative humidity decreased during the day, from 84% in the morning during Trial 1 to 49% in the mid-afternoon during Trial 5. Dry bulb temperature rose from 3.3 to 10.1 degrees Celsius during the trials. Table 2 also shows the average wind direction, average wind speed at 2m, average wind speed at 18.6m, and time of day for the five trials. The relative standard deviation of

these variables (defined as the ratio of standard deviation to the average) indicates a large degree of variability in the temperature and relative humidity data, but very little variability in the wind data.

Wind speed and direction were measured three times during each trial: one minute before start of spray (T-1), start of spray (T-0), and one minute after start of spray (T+1). The "average" wind speed given for 2m is an average of the three wind speed measurements made at the mast and the three made at the tower. The value given for wind speed at 18.6m is an average of the three measurements made at that height at the tower. The wind speed during the trials was fairly constant and low, not exceeding 2m/s for any of the trials.

Wind direction measurements at 2m (mast and tower) and 18.6m (tower) are shown in Table 3 for all five trials. As can be seen in Table 3, at a given location the three time measurements sometimes varied considerably. For example, for Trial 4, at the 2m mast location, the time measurements are 155 degrees at T-1, 145 degrees at T-0, and 180 degrees at T+1. For Trial 2, at the 18.6m tower location, the actual measurements are 115 degrees at T-1, 160 degrees at T-0, and 135 degrees at T+1. Wind direction measurements at the 18.6m tower location for Trials 4 and 5 show a similar degree of variability: Trial 4 measurements are 140 degrees at T-1, 165 degrees at T-0 and 120 degrees at T+1. Trial 5 measurements are 165, 145 and 135 degrees, respectively.

It is important to note that the actual (not average) wind direction measurements reflect a pattern observed by test personnel: for most of the morning, drainage winds moved downslope, but as the morning progressed the upper winds reversed and began blowing upslope (J. W. Barry, USDA Forest Service, private communication). Thus, winds at the release height (above 18.6 meters as described below) were probably different from the average wind measurements shown in Table 2, particularly later in the day. Although the wind measurements used in this analysis are the average values shown in Table 2, winds at release height may have given the spray cloud a different heading.

Additionally, it can be seen from Figure 1 that the direction of the slope of the terrain changed for each of the five card lines. This suggests that the average wind direction was probably different at each card line. Correcting for this effect, however, would have been difficult, although we did examine some sensitivity of the predictions to wind direction. Wind direction time history, especially in complex terrain spray situations, is critical if one wishes to understand spray drift in these types of application scenarios.

2.3 Spray Aircraft Configuration

The trials were conducted with a Bell G-3 helicopter. Forty-one Spraying System Number 80015 flat fan hydraulic nozzles were used. The nozzles were positioned on a boom located below the helicopter fuselage, perpendicular to the fuselage centerline.

Aircraft variables for each trial are given in Table 4. Aircraft heading was not indicated by either Barry (1974) or Dumbauld, Rafferty and Bjorklund (1977); however, headings can be determined from the topographic diagram shown in Figure 1. The pilot was instructed to base his heading on a sampling card number (in row 3, an open row, as given in Table 4) that was clearly marked for pilot recognition, and to fly the terrain contours. A flagger was used to help guide the pilot. The designated sampling card changed during the course of the day as winds became more upslope in direction. The intent was to capture the spray deposition within the sampling array.

2.4 Spray Characteristics

Aircraft altitude (spray release height) for Trial 1 was 45.7m AGL over the open rows and 15.2m over the forest rows. For all other trials, aircraft altitude was 38.1m over the open rows and 7.6m over the forest rows. Aircraft speed was reported to be constant for all the trials at 22.4 m/s.

Fuel oil with a density of 0.847 grams/cubic centimeter was sprayed at the rate of 6.06 gallons/minute (Dumbauld, Rafferty and Bjorklund 1977). The fuel oil contained Automate B Red Dye. The drop size characteristics for water sprayed from 8001 nozzles at a zero-degree angle are given in Table 5. This was the best approximation available to the actual spray material and spray system (Skyler and Barry 1991).

As previously mentioned, spray deposit cards were assessed following the spray pass with the ASCAS; deposition data are summarized in Barry (1974). Ground deposition data from each trial includes mass deposition in terms of volume per square meter, presented as milligrams per square meter (mg/sq m). These data are the basis for comparison with FSCBG predictions of deposition.

2.5 Results

The present document is the first examination of the Rennic Creek trials since Dumbauld, Rafferty and Bjorklund (1977) and is based entirely on that report, on field test data sheets included in Barry (1974), and on private communications with test personnel (J.W. Barry, USDA Forest Service).

Dumbauld, Rafferty and Bjorklund show predictions for ground deposition made by the H. E. Cramer Company, Inc. These predictions, which incorporated the Grim-Barry canopy penetration model previously referred to, can be found in Appendix A of their report. One of the conclusions reached by these authors was that further development and verification of the canopy penetration model should be undertaken. FSCBG is the aerial spray model which resulted from such efforts.

Other recommendations of interest were: that spray projects should be conducted in less complex terrain (in both open and forested areas) to develop confidence in aerial spray models; that inability to describe the spray cloud trajectory was a major difficulty in predicting drift in a complex terrain; and, that careful consideration should be given to the design of the sampling grid and the meteorological sampling network to better suit the purposes of model verification.

FIGURE 1: Test site at Rennic Creek. Sampling rows and meteorological measurement sites are shown. Forest is shown by the shaded area.

TABLE 1: Forest Characteristics at Rennic Creek.

Parameter	Story 1	Story 2	Story 3
Average tree height (m)	19	13	8
Average stand density (stems/acre)	95	95	95
Tree envelope widths in 1m intervals (m):			
1	0.30	0.25	0.20
2	0.30	0.25	0.20
3	0.30	0.25	0.20
4	0.30	0.25	2.31
5	0.30	0.25	1.77
6	0.30	0.25	1.22
7	0.30	0.25	0.67
8	0.30	0.25	0.13
9	0.30	2.50	
10	0.30	1.88	
11	4.23	1.26	
12	3.71	0.64	
13	3.20	0.02	
14	2.68		
15	2.16		
16	1.64		
17	1.12		
18	0.61		
19	0.09		

TABLE 2: Summary of Meteorology Data for the Rennic Creek Trials.

Trial #	Local Time	Dry Bulb Temp. (deg C)	Relative Humidity (%)	Average Wind Speed at 2m (m/s)	Average Wind Speed at 18.6m (m/s)	Average Wind Direction (degrees)
1	1032	3.3	84	1.93	1.79	130
2	1149	6.7	66	1.79	1.79	140
3	1300	8.3	64	1.79	1.79	142
4	1406	9.4	51	1.79	1.64	136
5	1457	10.1	49	1.64	1.64	147
Average:		7.6	63	1.79	1.73	139
Relative Standard Deviation:		0.32	0.20	0.05	0.04	0.04

TABLE 3: Wind Direction at Specific Heights for the Rennic Creek Trials.

Location		Trial 1 local time: 1032	Trial 2 local time: 1149	Trial 3 local time: 1300	Trial 4 local time: 1406	Trial 5 local time: 1457
2-Meter Mast (forest)						
Wind direction at:	T-1	135	095	165	155	130
	T-0	135	180	150	145	155
	T+1	165	170	170	180	145
2-Meter Tower (open)						
Wind direction at:	T-1	120	140	140	125	150
	T-0	130	150	115	125	140
	T+1	135	130	145	130	135
18.6-Meter Tower (open)						
Wind direction at:	T-1	125	115	155	140	165
	T-0	125	160	140	165	145
	T+1	135	135	145	120	135

Note: Wind direction measurements shown are in degrees, and times T-1, T-0, and T+1 are in minutes.

TABLE 4: Aircraft Variables and Position for the Rennic Creek Trials.

Trial #	Aircraft Altitude, Open Rows (m)	Aircraft Altitude, Forest Rows (m)	Position Over Row #3 (sampler #)
1	45.7	15.2	14
2	38.1	7.6	21
3	38.1	7.6	21
4	38.1	7.6	23-24
5	38.1	7.6	26

TABLE 5: Drop Size Characteristics for Dyed Fuel Oil in an 8001 Hydraulic Nozzle.

Average Diameter (micrometers)	Mass Fraction
45.88	0.0112
73.78	0.0230
106.35	0.0669
138.62	0.1391
171.03	0.1691
203.42	0.1679
235.88	0.1441
268.32	0.1095
301.32	0.0869
334.77	0.0434
366.72	0.0228
398.21	0.0061
430.71	0.0058
463.18	0.0040
495.68	0.0002
Total	1.0000

VMD = 204 micrometers

3. FSCBG Simulation of Field Test Data

The objective of the evaluation reported here is to compare FSCBG predictions of deposition both with canopy and without canopy with the field test deposition data cited. A detailed description of input parameters necessary for FSCBG modeling may be found in Teske and Curbishley (1991).

Aircraft altitude and heading, wind speed, relative humidity and temperature vary for each trial according to the field test data as previously shown in Tables 2 and 4. Aircraft heading is along the contours of the terrain with the aircraft flown perpendicular to the wind.

Aircraft configuration and powerplant data required by FSCBG are summarized in Table 6. FSCBG version 4.3 (Teske and Curbishley 1994) contains a version of the Bell G-3 in its library of standard aircraft configurations. Forty-one hydraulic nozzles are placed evenly along the boom as previously described.

Drop size characteristics used to generate FSCBG predictions of deposition for the dyed fuel oil are as shown in Table 5. Note that the drop size characteristics used in FSCBG simulations of this field test are not exactly representative of the actual spray system used during the test. The nozzles were type 80015 and the spray material was fuel oil, not water (the exact type of fuel oil is not described in the available reference material). It should be noted that in our previous papers (particularly MacNichol and Teske 1993a and 1993b) the importance of accurate modeling of drop size characteristics was stressed. Unfortunately, the Rennic Creek study was conducted in 1974, and it can not be expected that all information necessary to accurately model the study would have been collected before aerial spray models were developed.

Because three of the sampler rows were in forested areas, FSCBG predictions were generated twice for each trial, once with no canopy effect and once with a canopy modeled according to the forest characteristics given in Table 1. Deposition data measured from sampler rows 1, 2, and 3 (open rows) are simulated without a canopy and deposition data from rows 4, 5, and 6 (forest rows) are simulated with a canopy.

TABLE 6: Aircraft Characteristics for the Bell G-3 Helicopter.

Aircraft	Bell G-3
Type	Helicopter
Weight	11050.0 kg
Rotor diameter	11.28 m
Blade RPM	374.00

4. Results and Discussion

Comparison plots of field test deposition data and FSCBG deposition predictions for open terrain and forest terrain for each of the five trials are presented in the Appendix. The deposition variable examined is mass, in milligrams per square meter (mg/sq m). As previously mentioned, each trial in the field test consisted of a spray run over six parallel sampler lines; meteorological conditions and spray variables are assumed to be identical for all sampler lines, but three were in open terrain and three were under the forest canopy. Thus, two sets of deposition data (labeled for open or forest terrain) exist for each trial. FSCBG simulations are plotted as solid lines and field test data are plotted as open circles, squares and diamonds for rows 1, 2, and 3, respectively (or for rows 4, 5, and 6 in forest terrain).

FSCBG generates deposition data along a line perpendicular to the aircraft flight path; this line is not always oriented along the field test sampler line. Since aircraft heading over each row is not specified, it is assumed that the FSCBG prediction is indeed oriented along the field test sampler lines. However, a change in aircraft heading over each row could significantly affect the FSCBG predictions shown.

Deposition data from each row during a trial has been adjusted to reflect the probable position of the helicopter over that row. Despite this adjustment, note that deposition data measured from the three rows in each type of terrain do not show identical patterns of deposition. The scatter seen in the deposition data for a given terrain type and a given trial is probably due to several factors.

1. Although it is known that the helicopter flew over a specified position on row 3 while flying the terrain contours shown in Figure 1, the position of the aircraft centerline over rows 1, 2, 4, 5, and 6 was arrived at through examination of Figure 1 and not from actual measurements made during the test.

2. Meteorological, aircraft and spray conditions during the trials may not be adequately represented by the data available in Dumbauld, Rafferty and Bjorklund (1977) and Barry (1974), or by the averaging technique employed here. The total area covered by the six rows of sampler cards is large (at least 13 acres) and meteorological measurements as well as aircraft and spray system variables are not defined in great detail. Meteorological data were only recorded in two places, near the center of the test area and near the edge of the forest. The actual test conditions probably varied over each of the six card rows, and were probably different under the canopy and at the extreme edges of the test area.

Furthermore, there is no way to assess the accuracy of the meteorological, aircraft and spray system measurements tabulated in the data sheets (Barry 1974).

3. The assumption was made that test conditions were constant over the test area: in other words, that meteorology in the open and forested areas was the same. This assumption has been questioned by several researchers (Thistle, Teskė and Barry 1994), but it is the best that can be made with the data available.

4. The forest canopy was described in terms of its overall aspects over the forested portion of the test area; however, the stands of trees over and near the sampler rows may not have been adequately described by these general characteristics. Dumbauld, Rafferty and Bjorklund (1977) reported that approximately half of the trees in the

forested area had minimal foliage on the day of the trials, so the canopy over certain areas may have been atypical for the forest.

5. Since the method of gathering and evaluating deposition data from the sampler cards is not described in any detail, there may be some inaccuracies in the data sheets used to plot field test ground deposition (the data sheets are from Barry 1974).

These sources of error represent both measurement error and uncertainties in the test design and description. All of these factors will affect the accuracy of the FSCBG modeling described in the previous section.

The accuracy of FSCBG modeling of the Rennic Creek trials is also affected by the complex terrain described in Dumbauld, Rafferty and Bjorklund (1977). A complex terrain model capable of simulating an area the size of the Rennic Creek drainage is not available, nor were corrections made for the downslope terrain. VALDRIFT, a complex terrain model currently under development and to be implemented in FSCBG (Allwine, Bian and Whiteman 1993), would unfortunately not be applicable to an area as small as Rennic Creek.

Each of the comparison plots is briefly evaluated below. The aircraft centerline is assumed to be at a distance = 0, with negative distance to the left of the aircraft centerline and positive distance to the right. As previously mentioned, the helicopter did not fly over the center of each row, and the only data available as to aircraft position over the rows is given in Table 4.

Qualitatively, the FSCBG model predictions do a very good job of simulating ground deposition for most of the Rennic Creek trials, particularly over open terrain. In light of the possible sources of error in modeling the trials (which have been enumerated above), FSCBG predictions are particularly good.

The plots of field test deposition data show some inconsistencies which should be noted. Table 7 shows the maximum value of mass deposition for open terrain and forest terrain for each trial. In Trials 1 and 3, deposition under the forest canopy was greater than deposition in open terrain. In Trial 5, the canopy had only a minimal effect, while in Trial 2 there was almost no deposition in forest terrain.

Field test data from Trial 2 shows the effect of abrupt shifts in wind conditions. Trials 2 and 3 were conducted only an hour and 10 minutes apart and at essentially identical conditions (according to available meteorological and spray system data), with the exception of wind direction, which shifted abruptly between T-1 and T-0 during Trial 2 (see Table 3). The apparent effect of this shift can be seen in the plots of field test data from these two trials (see Appendix): deposition levels vary dramatically between the two trials. The wind shift, and the discrepancy in measured deposition, is particularly striking under the forest canopy. It is apparent that the assumptions made in modeling the remaining four trials do not adequately simulate conditions under the canopy during Trial 2 (modeling with average wind direction does not adequately simulate the abrupt wind shift measured by the 2m mast). For this reason the data from Trial 2, forest terrain, is not included in the calculation of correlation coefficients.

There are some inconsistencies in field test deposition measurements from row to row in each trial. These differences could be due in part to the many sources of error listed above. Correlation coefficients (R^2) are calculated using the envelope of field test deposition data rather than data from a specific row.

It is important to note that the deposition measured in forest terrain was affected by two other factors that were observed during the test (J. W. Barry, USDA Forest Service, private communication). Atmospheric turbulence over the test area caused the smaller drops in the spray to remain aloft above the canopy. Secondly, deposition was determined by estimating mass deposited on the sample cards as opposed to number of drops deposited. There were probably damp cards in the forest area (more so than in the open area), and drop spreading on damp cards would have resulted in an over estimate of deposition. Thus, the mass deposition measured in forest terrain (shown in Table 7) may be higher than the actual mass deposition that occurred.

Table 8 contains the correlation coefficients comparing the field test data (mg per sq m) with FSCBG predictions. This table gives a quick summary of the test results and corresponding FSCBG predictions. For each trial, the correlation coefficient R^2 was calculated by comparing the envelope of field test deposition with FSCBG predicted deposition. The average correlation for each type of terrain is also shown in Table 8.

The quantitative measure of correlation coefficient reduces the comparison to a single number, which may not entirely reflect the quality of the prediction. However, in this case the correlation coefficients calculated for the five Rennic Creek trials reflect the good quality of the FSCBG predictions, ranging from $R^2 = 0.79$ for Trial 5, forest terrain, to $R^2 = 0.93$ for Trials 2, open terrain, and 4, open terrain. Each trial shows similar correlation for deposition predictions in forested and open terrain. As previously stated, Trial 2, forest terrain, was not included in the correlation calculations.

The average correlation for the trials is $R^2 = 0.88$ for the rows in open terrain and $R^2 = 0.85$ for rows in forest terrain. For all of the trials over both types of terrain, the average correlation coefficient is $R^2 = 0.86$. This value compares favorably with other FSCBG model comparisons undertaken recently (MacNichol and Teske 1993a, 1993b,1994).

TABLE 7: Maximum field test values of mass deposition for each trial for open and forest terrain.

Trial #	Max deposition, Open Terrain (mg/sq m)	Max deposition, Forest Terrain (mg/sq m)
1	176	182
2	240	22
3	153	193
4	166	82
5	136	113

TABLE 8: Correlation coefficients for Trials 1 through 5 (open terrain and forest terrain) comparing field data and FSCBG predictions for mass deposited.

Trial #	Correlation to mass	Comments
1, Open	0.90	
1, Forest	0.85	
2, Open	0.93	
2, Forest	-----	Small amount of mass deposited.
3, Open	0.81	
3, Forest	0.87	
4, Open	0.93	
4, Forest	0.90	
5, Open	0.81	
5, Forest	0.79	
Average, Open	0.88	
Average, Forest	0.85	
Overall Average	0.86	

5. Conclusions and Recommendations

FSCBG predictions of the 1974 Rennic Creek trials ground deposition data show very good correlation, with an overall R^2=0.86 for mass. This value is well above the acceptable level for operational field tests. However, predicted deposition would probably have been even better with the following data available:

1. exact drop size characteristics.
2. a more thorough description of the aircraft flight path over the sampler rows.
3. more detailed meteorological data over the entire test area.
4. more detailed measurement of aircraft and spray system variables.
5. a more exact description of the forest canopy immediately above the sampler rows.
6. a more precise method of deposition sampling.

FSCBG predictions for field data in forest terrain are very similar to predictions for data in open terrain, and are particularly good considering the large amount of scatter in the field test data itself. However, further analysis of field test deposition data in forest terrain is recommended in order to further validate FSCBG simulation of deposition under a canopy, and the implementation of a complex terrain model into FSCBG is encouraged. There is also a need to thoroughly evaluate the influence of winds on deposition, particularly wind profiles that include large changes in direction or speed over the test area.

As recommended in our previous FSCBG model comparison reports (MacNichol and Teske 1993b and 1994), further wind tunnel testing should be done to expand the existing database of drop size characteristics available to FSCBG users. The need for accurate drop size characteristics (accurately defined with respect to all spray system variables) applies not only to formulations currently in use by the USDA Forest Service, but also to such basic spray materials as fuel oil and water in a variety of spray systems.

Also as previously recommended, test plan additions such as detailed meteorological measurements, multiple measurements of aircraft and spray variables during each trial, and timely and accurate interpretation of deposition cards should be incorporated into all future field tests (MacNichol and Teske 1994).

6. Acknowledgment

The authors and John W. Barry recognize the contributions of the USDA Forest Service (FS) employees who contributed to the success of the field test. Bob Ekblad, FS, retired engineer, Missoula Technology Development Center (MTDC), selected the site and arranged for technical and logistical support. Field support was provided by Lynn Marasillis, Ben Lowman, Don Weatherhead, and Don Lassila. We also recognize Fred Gerlach, our expert pilot and well-known professor of forestry, University of Montana. Lastly, we recognize the technical support provided by the U.S. Army Dugway Proving Ground, Utah, that included weather observations.

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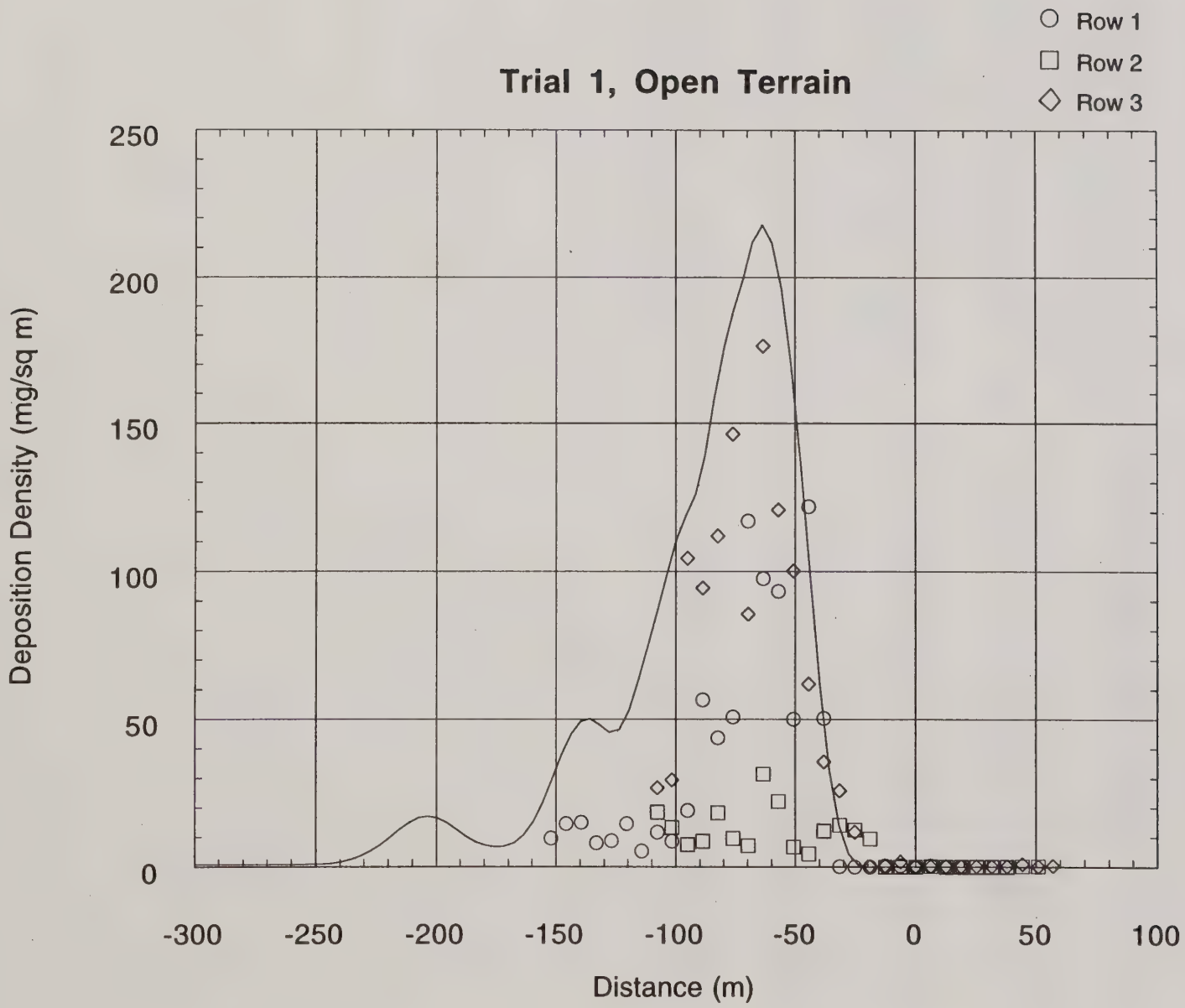
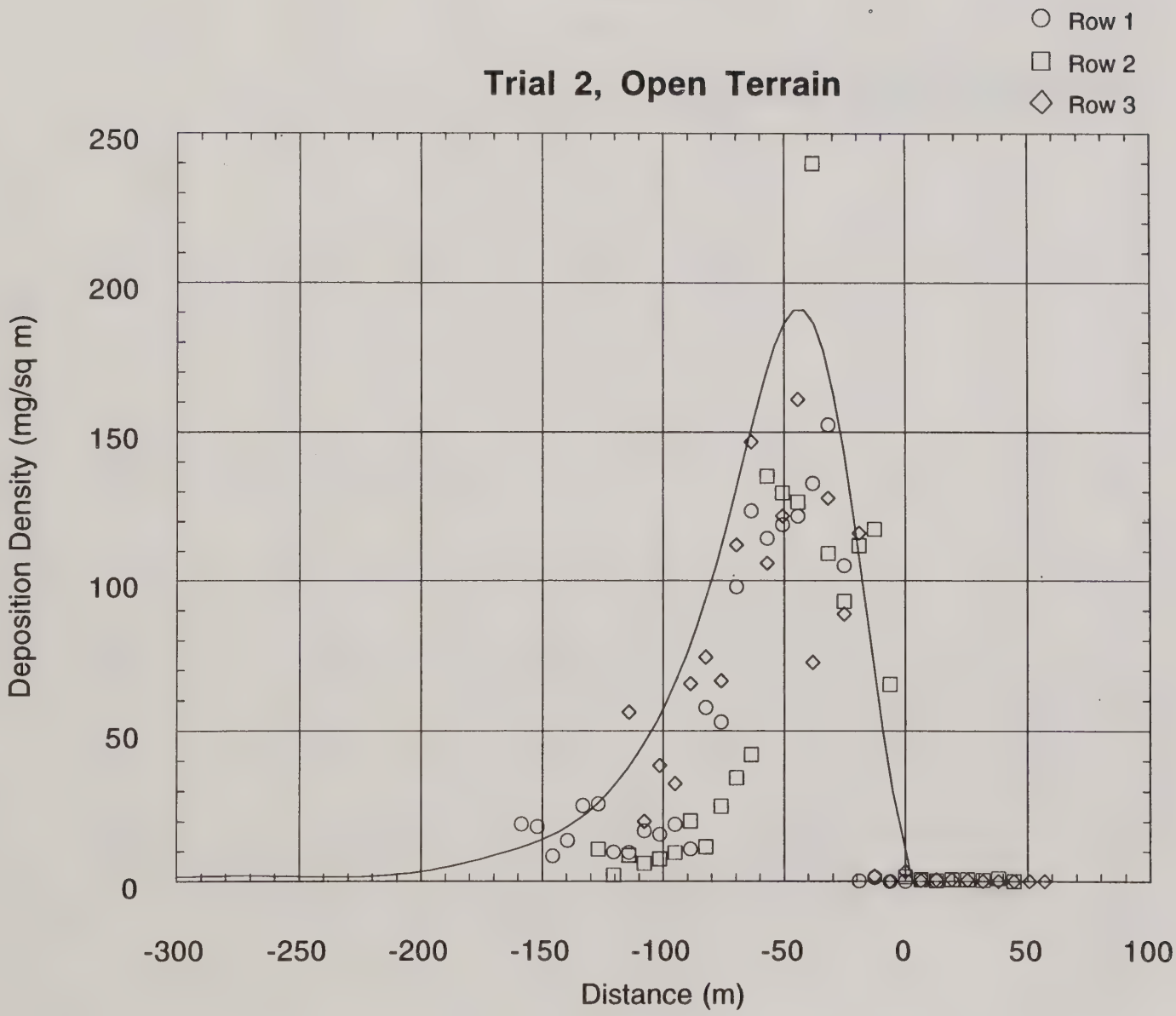
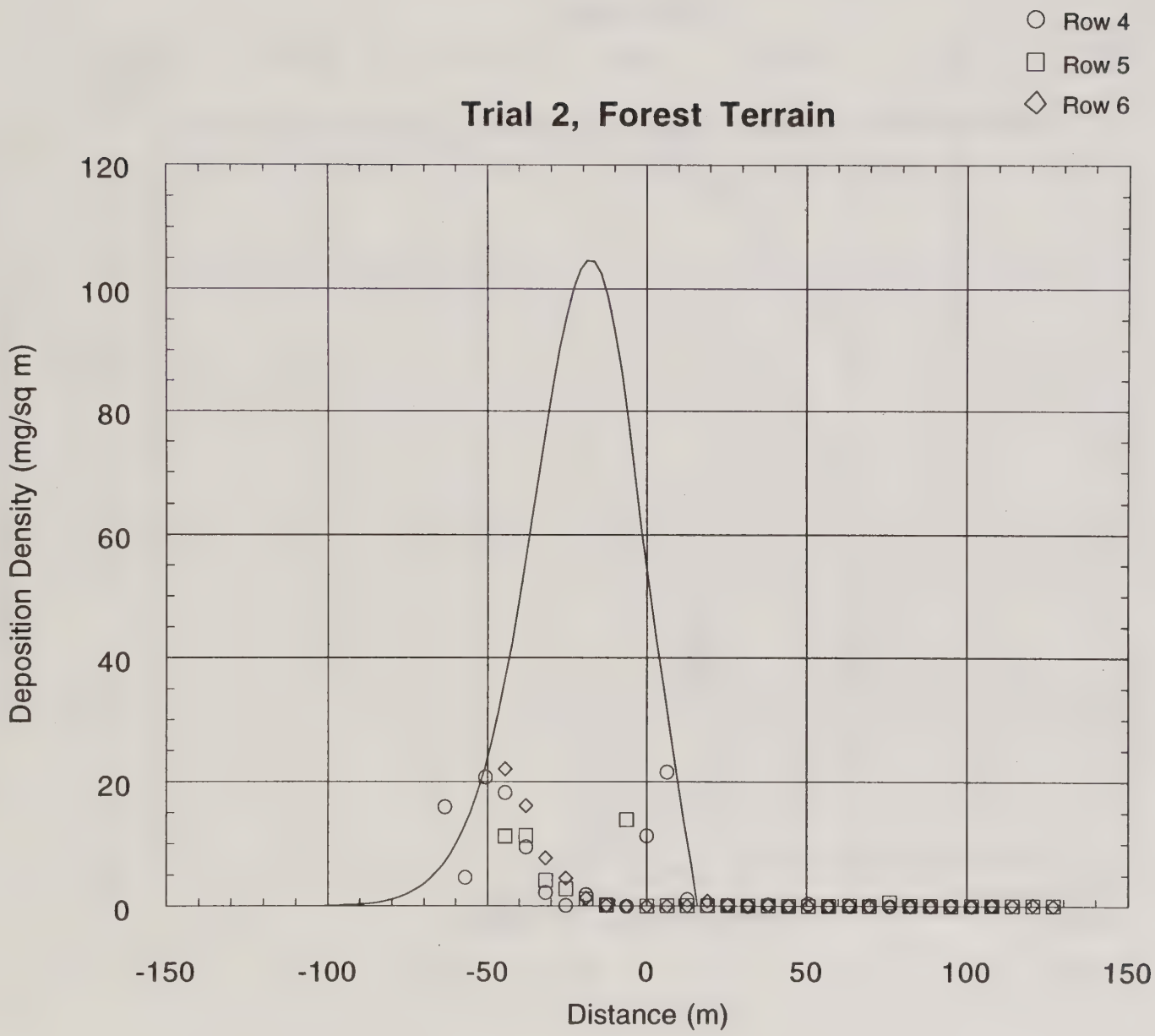
Appendix

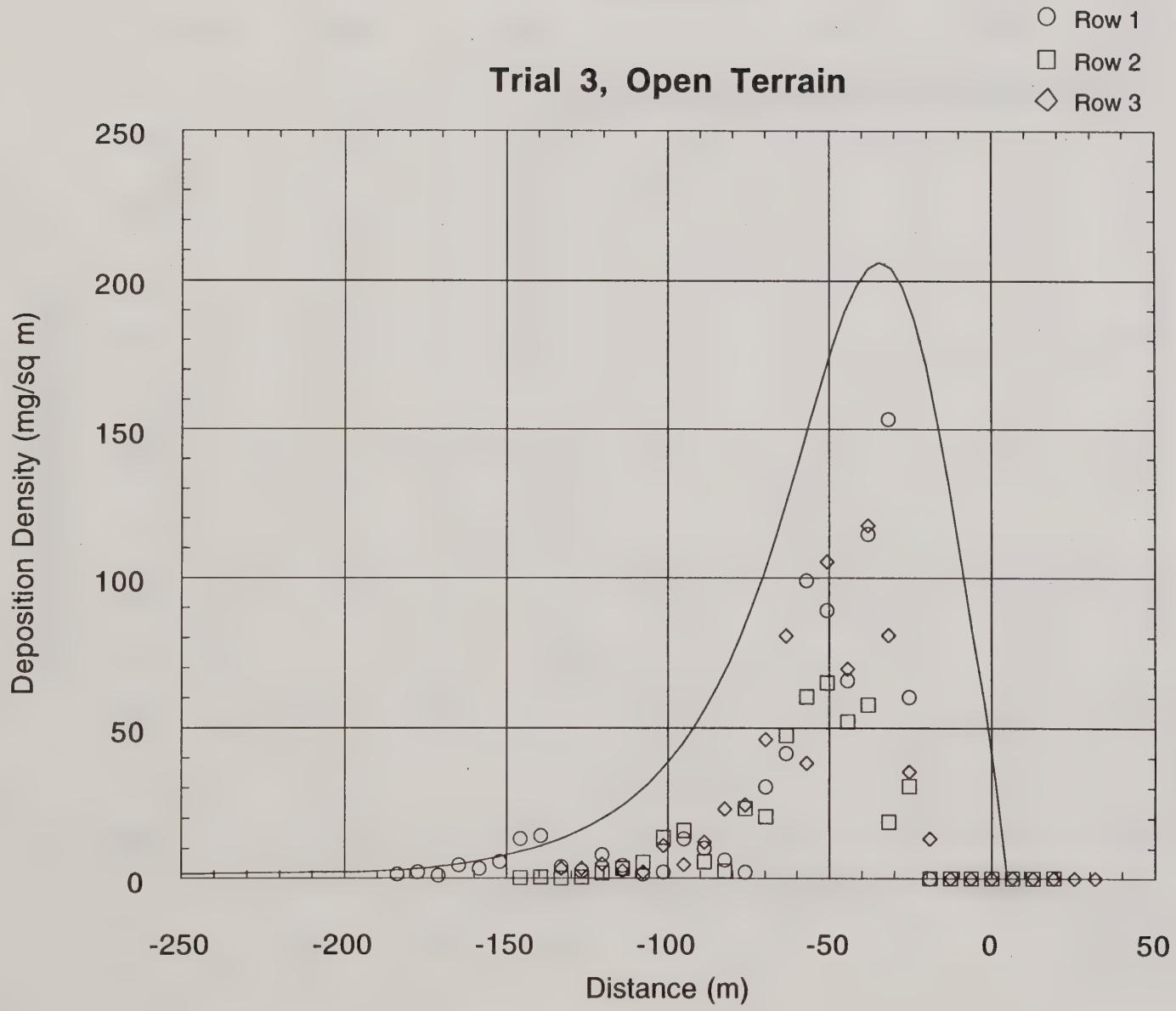
The Appendix contains a plot of deposition density in mg/sq m for open terrain and one for forest terrain for each of the five Rennic Creek trials. The three rows of field data are shown as symbols and FSCBG predictions as solid lines.


Trial 1, Open Terrain
Row 1
Row 2
Row 3
Deposition Density (mg/sq m)
250
200
150
100
50
0
-300
-250
-200
-150
-100
-50
0
50
100
Distance (m)

Row 4
Row 5
Row 6
Trial 1, Forest Terrain
Deposition Density (mg/sq m)
200
150
100
50
0
-200
-150
-100
-50
0
50
100
150
Distance (m)


Trial 2, Open Terrain
Row 1
Row 2
Row 3
Deposition Density (mg/sq m)
250
200
150
100
50
0
-300
-250
-200
-150
-100
-50
0
50
100
Distance (m)


Row 4
Row 5
Row 6
Trial 2, Forest Terrain
120
100
80
60
40
20
0
Deposition Density (mg/sq m)
-150
-100
-50
0
50
100
150
Distance (m)


Trial 3, Open Terrain
Row 1
Row 2
Row 3
Deposition Density (mg/sq m)
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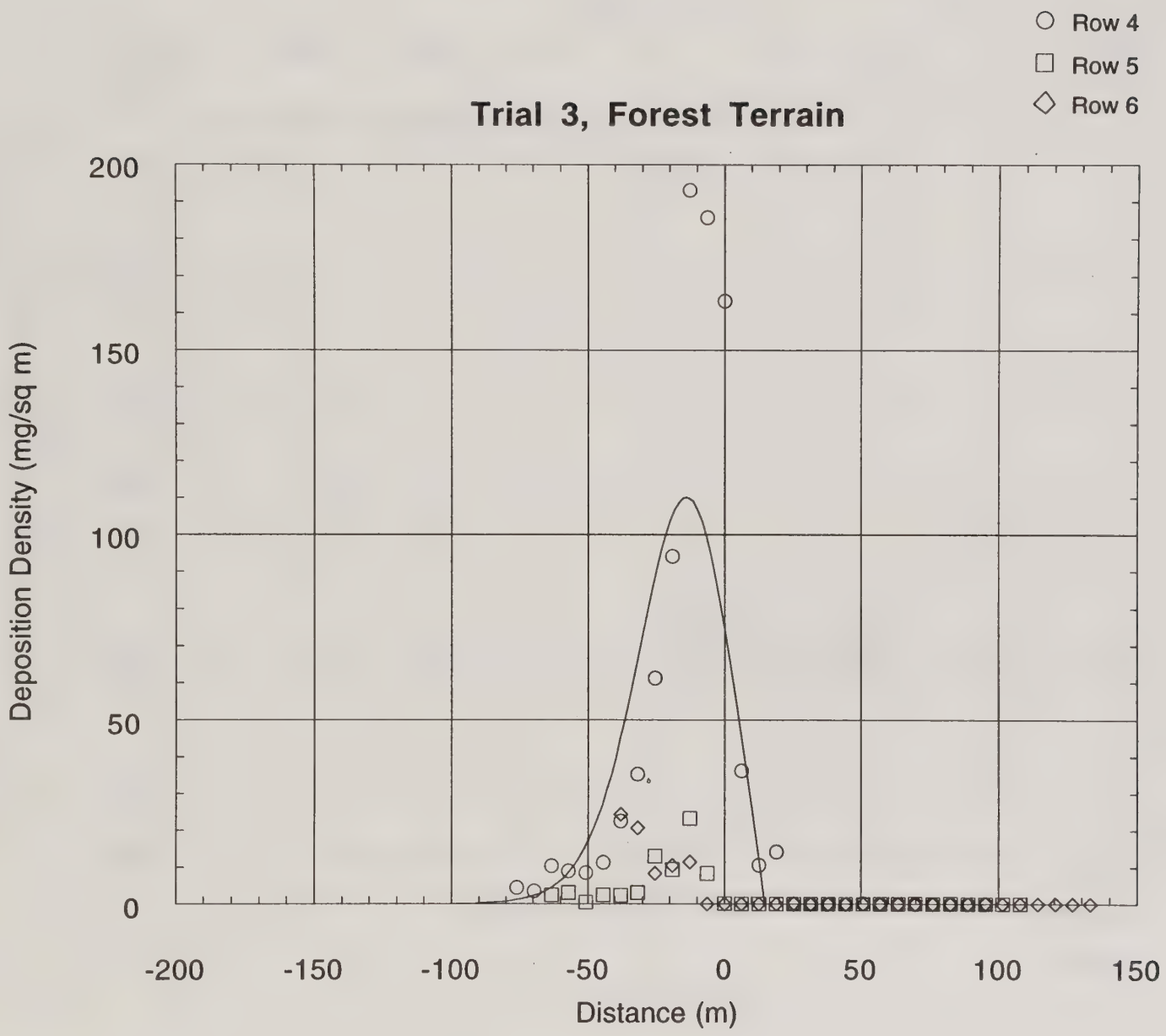
200
150
100
50
0
-250
-200
-150
-100
-50
0
50
Distance (m)


Row 4
Row 5
Row 6
Trial 3, Forest Terrain
Deposition Density (mg/sq m)
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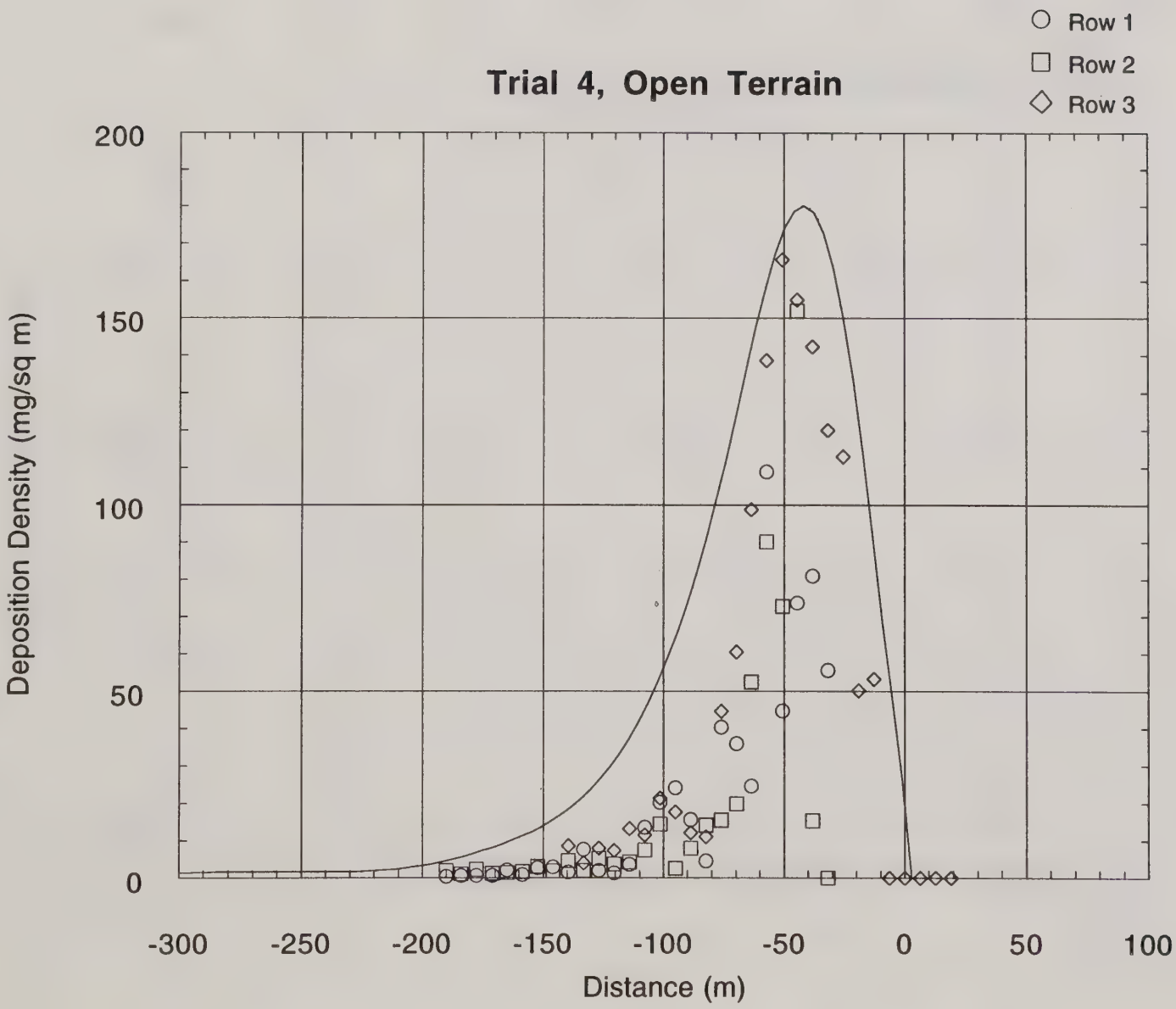
150
100
50
0
-200
-150
-100
-50
0
50
100
150
Distance (m)


Trial 4, Open Terrain
Row 1
Row 2
Row 3
Deposition Density (mg/sq m)
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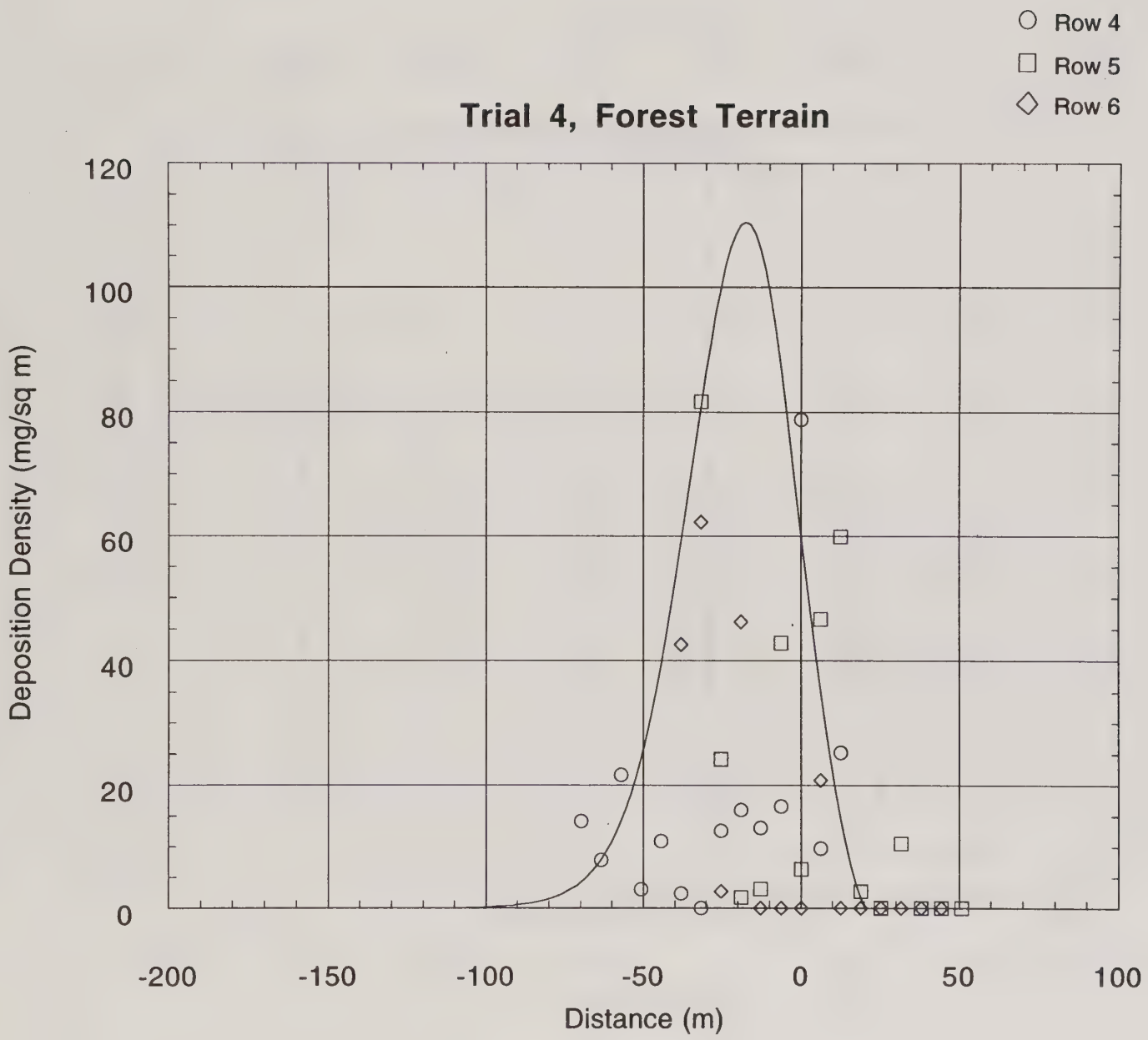
150
100
50
0
-300
-250
-200
-150
-100
-50
0
50
100
Distance (m)


Row 4
Row 5
Row 6
Trial 4, Forest Terrain
Deposition Density (mg/sq m)
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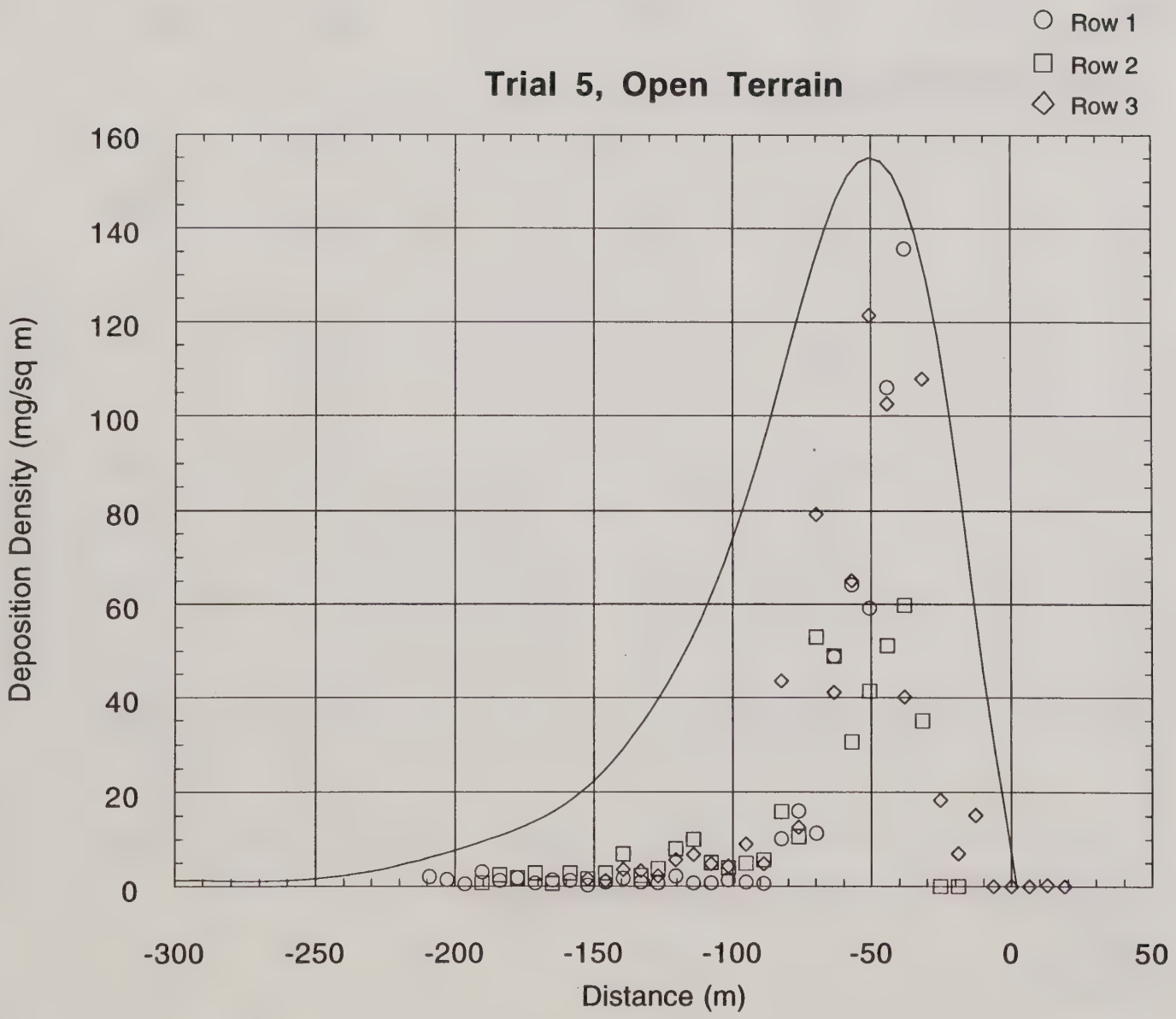
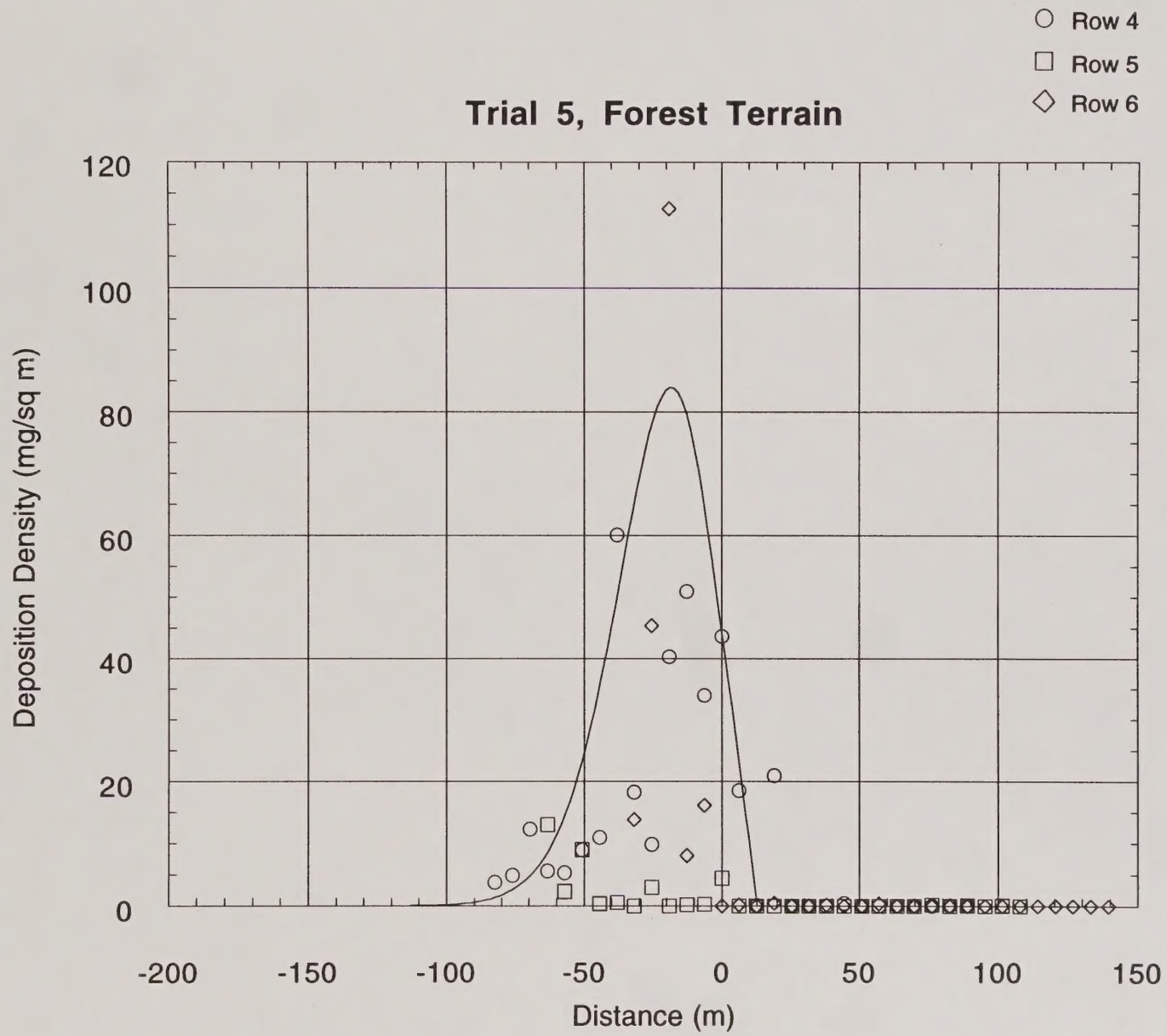
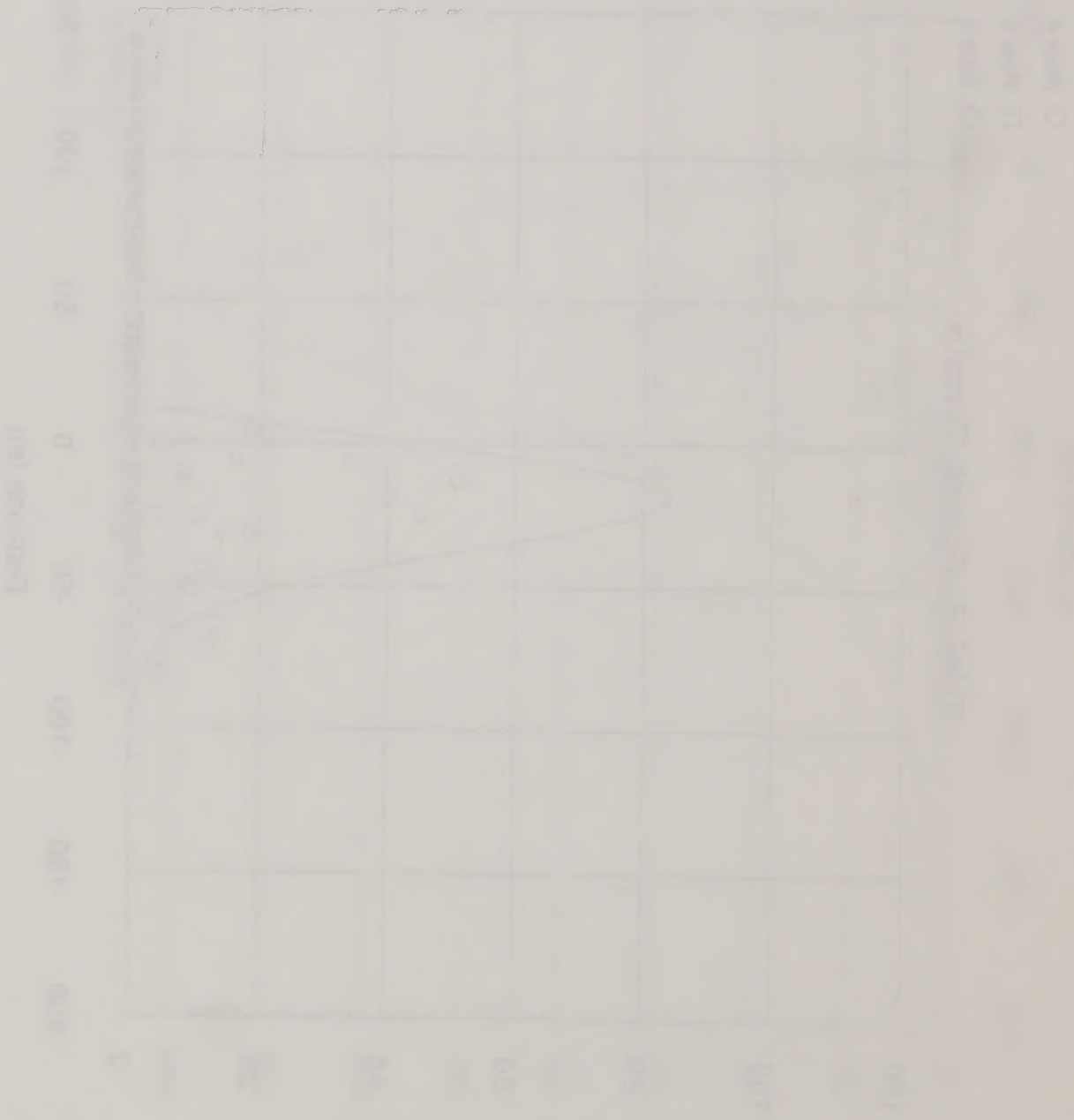
100
80
60
40
20
0
-200
-150
-100
-50
0
50
100
Distance (m)


Trial 5, Open Terrain
Row 1
Row 2
Row 3
Deposition Density (mg/sq m)
160
140
120
100
80
60
40
20
0
-300
-250
-200
-150
-100
-50
0
50
Distance (m)


Row 4
Row 5
Row 6
Trial 5, Forest Terrain
Deposition Density (mg/sq m)
120
100
80
60
40
20
0
-200
-150
-100
-50
0
50
100
150
Distance (m)



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